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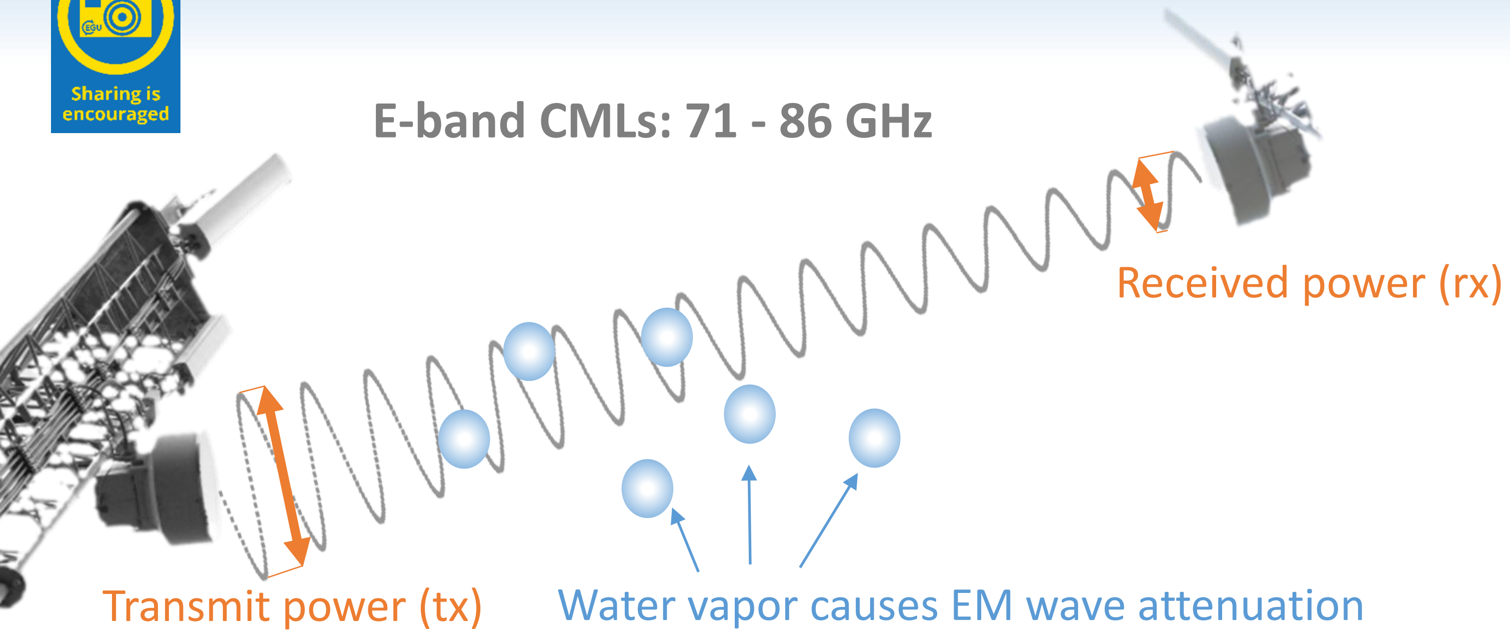
Water vapor monitoring with E-band microwave links of cellular backhaul



Commercial microwave links (CMLs) are point-to-point radio connections forming backbone of cellular networks

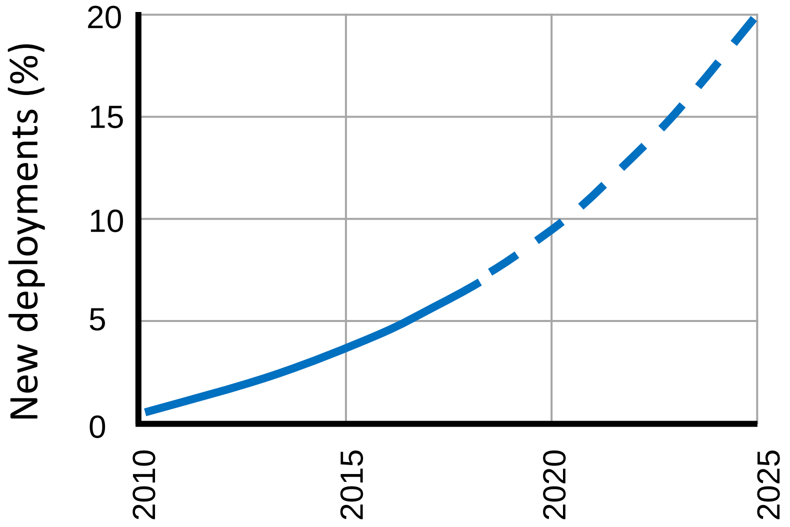
Highlights:

- E-band CMLs accurately observe water vapor density in the atmosphere
- Observations from hundreds of devices are collected in real time from one location
- Most common dual-frequency setup is useful for quality control

- **How to exploit attenuation data from new generation of commercial microwave links (CMLs) operating at E-band?**
- **Can we use them as unintentional water vapor sensors?**

E-band commercial microwave links – thousands of potential water vapor sensors

- E-band CMLs (71 – 86 GHz) are rapidly deployed in cellular networks worldwide
- We currently collect power losses from 700 E-band (and 1700 K-band) CMLs in the Czech Republic to use them as rainfall and water vapor sensors
- E-band CMLs are more sensitive to water vapor than CMLs operating around 22-23 GHz for which water vapor retrieval was originally proposed
- However, E-band CMLs are also sensitive to other variables and phenomena such as temperature or dew



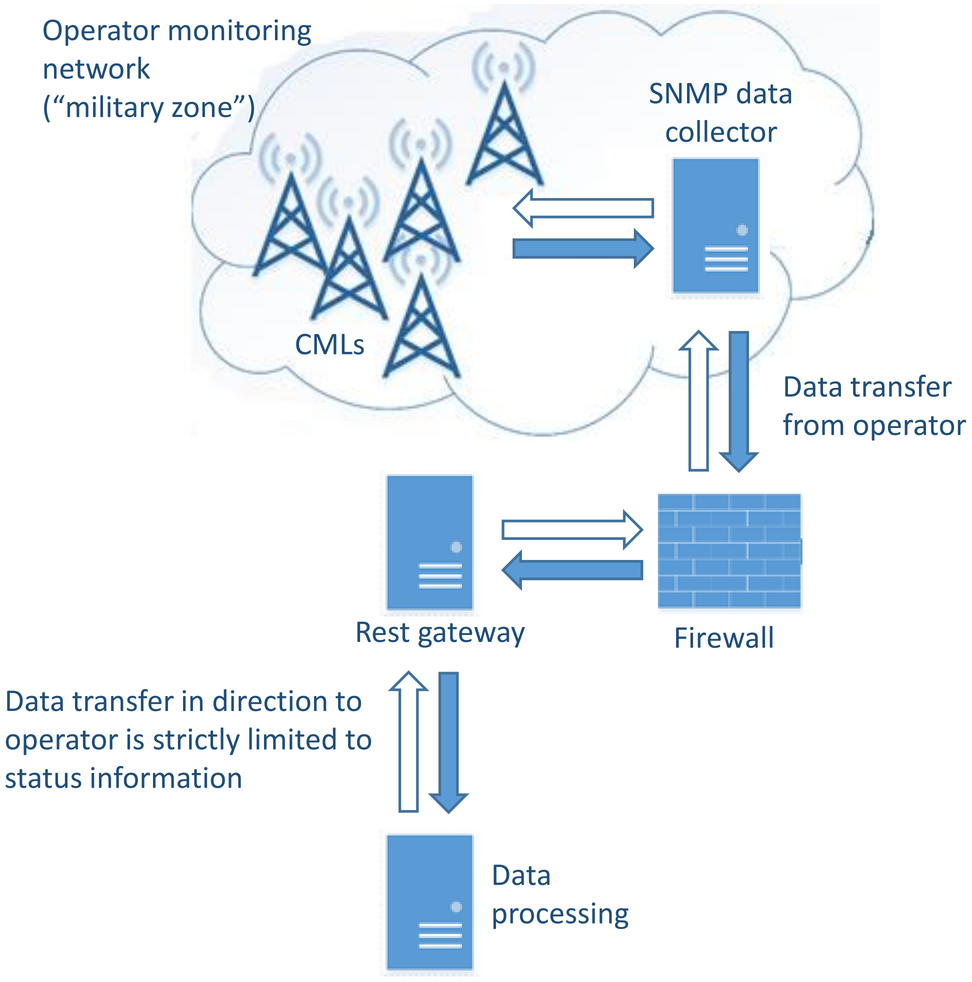
New deployments of E-band CMLs globally
Ericsson Microwave Outlook (2019)

This contribution presents the first quantitative evaluation of E-band CMLs used as unintentional water vapor sensors

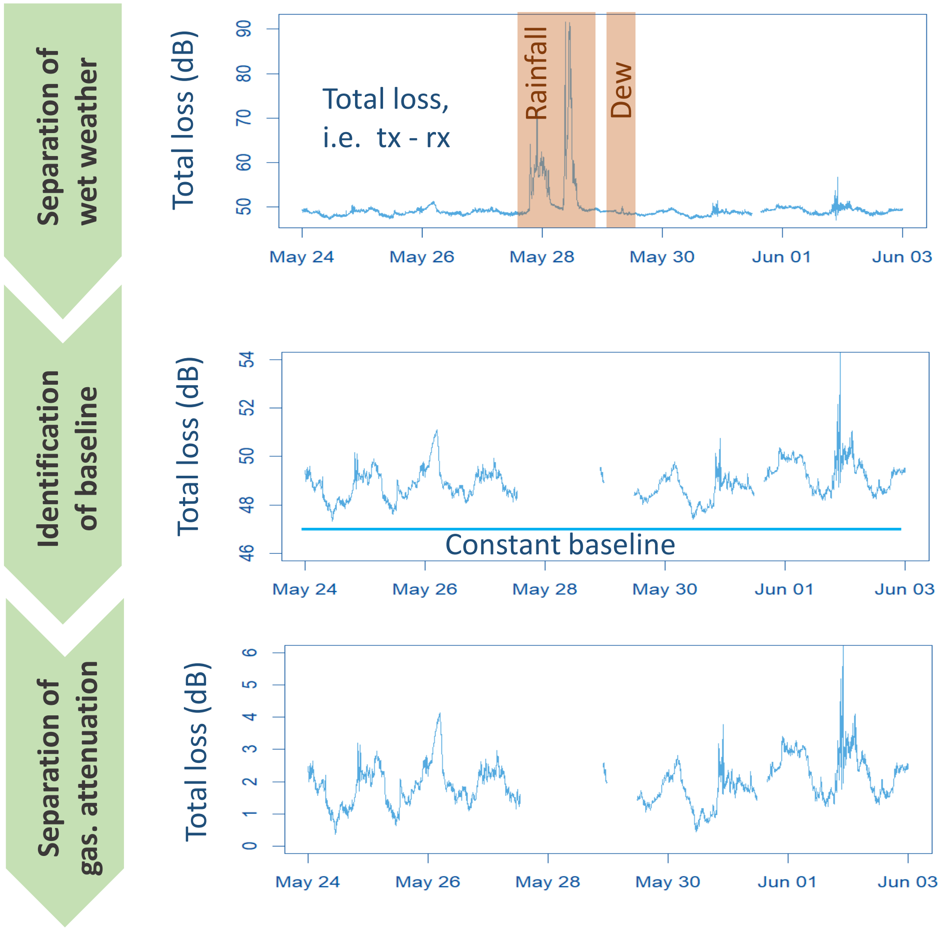
8000 E-band CMLs are currently registered in the Czech Republic (78 900 km^2) and 2000 longer 2 km

Data acquisition and processing – Czech Republic

System architecture



Processing



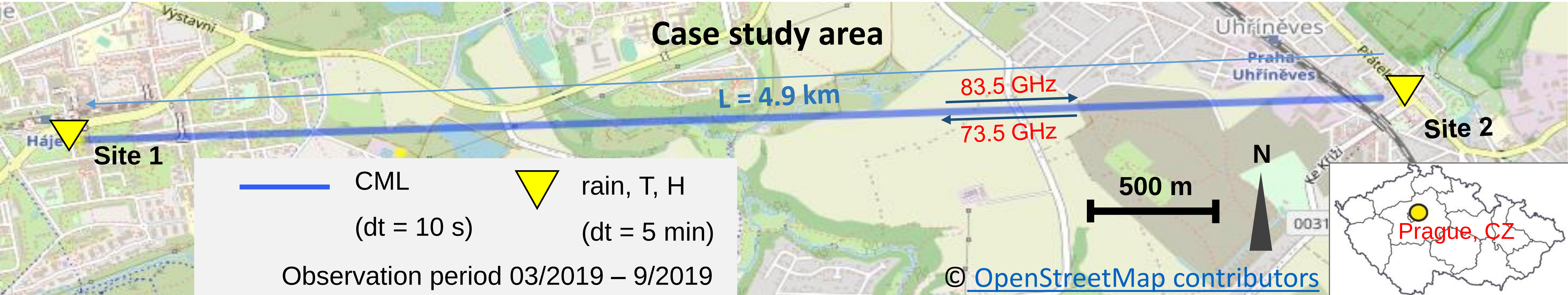
Theoretical framework and experimental setup

Water vapor retrieval

1. **Obtain empirical parameters by fitting our model to mechanistic model of Liebe (1993)**
2. **Separate gaseous attenuation from observed total loss:** $k_{gas} = \frac{tx - rx - B}{L}$ $\quad B = med(tx - rx) - med(k_{gas\_expect})$
3. **Calculate dry-air attenuation for temperature *T*:** $k_{air} = \frac{T}{20}\left(k_{air(T=0°C)} - k_{air(T=20°C)}\right) + k_{air(T=20°C)}$
4. **Convert gas. attenuation to water vapor attenuation corresponding to temperature *T*:** $k_{wv(T=10°C)} = \left(k_{gas} - k_{air}(T)\right)\left(1 - \frac{\epsilon}{T - 10}\right)$
5. **Convert water vapor attenuation to water vapor density:** $\Omega = \gamma\, k_{wv(T=10°C)}{}^{\delta}$

ϵ, δ, γ: empirical parameters

$k_{air(T=0,20°)}$: from attenuation model of Liebe (1993)



Water vapor retrieval performance

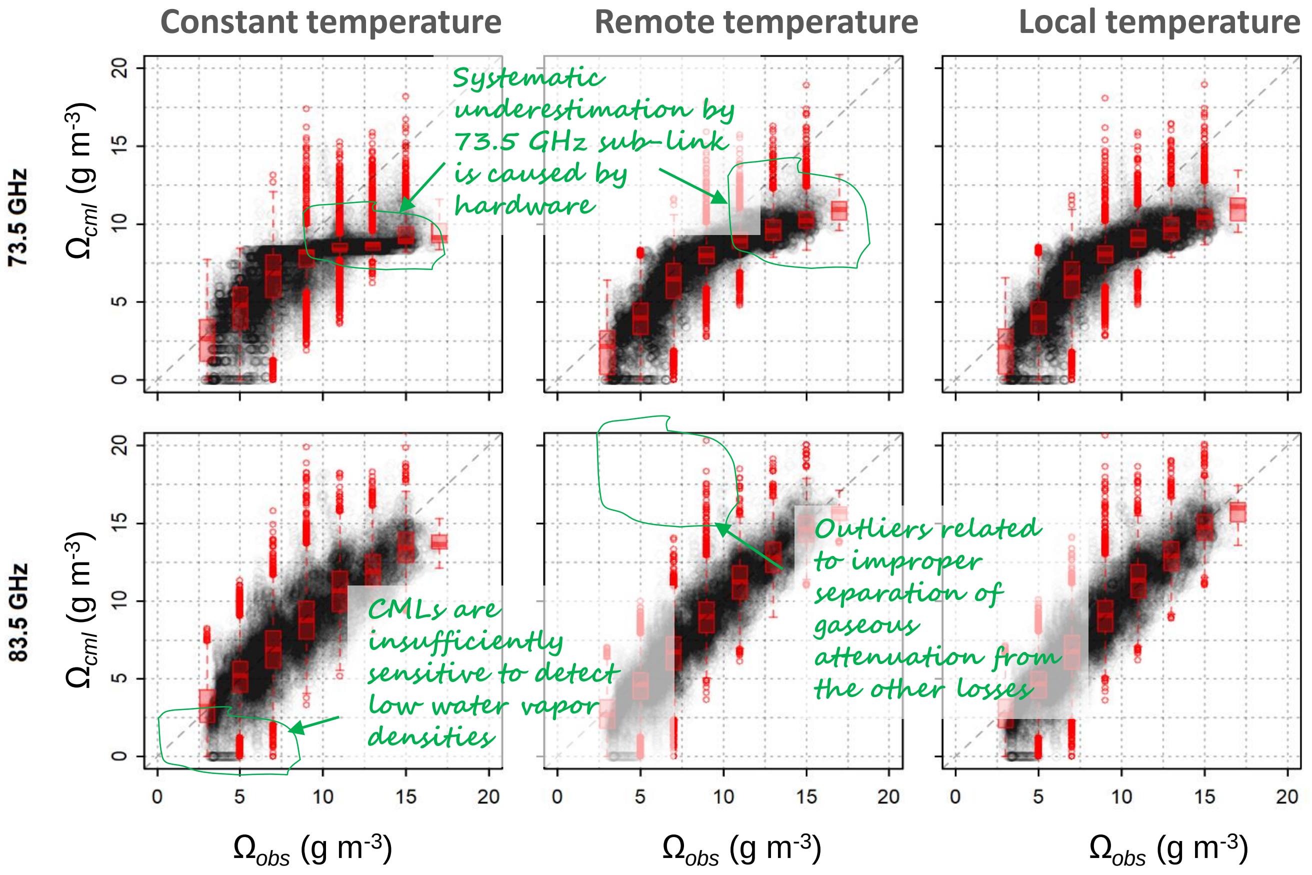
Evaluated only for dry weather with safety window of 6 hours before and after any rain-gauge tip (65 % of time)

Assessed for three temperature inputs:

1. Constant (mean *T* over evaluation period)
2. *T* from remote meteo station (hourly data)
3. Local temperature (5-min data)

	T source	RMSE ($g\ m^{-3}$)	Rel. err. ($g\ m^{-3}$)	R^2 (-)
73.5 GHz	T_{const}	2.65	-0.20	0.56
	T_{remo}	2.30	-0.19	0.72
	T_{local}	2.26	-0.18	0.72
83.5 GHz	T_{const}	1.74	-0.04	0.74
	T_{remo}	1.46	-0.03	0.85
	T_{local}	1.48	-0.02	0.85

Observed vs. CML based water vapor



Conclusion

- Long E-band CMLs can be used as unintentional sensors of water vapor
- 83.5 GHz frequency is more sensitive to water vapor than 73.5 GHz frequency and thus also more suitable for water vapor retrieval
- Reliable separation of gaseous attenuation from observed total loss is crucial for accurate estimates

Next steps:

- The method will be tested on larger set of CMLs. We currently collect data from 500 E-band CMLs longer than 2 km by which we expect sufficient sensitivity to water vapor
- Dual-frequency setup (common to all collected CMLs) will be used for identifying outliers

References

For more information on atmospheric observations with E-band CMLs see:

Fencl, M., Dohnal, M., Valtr, P., Grabner, M., and Bareš, V.: Atmospheric observations with E-band microwave links – challenges and opportunities, *Atmospheric Meas. Tech.*, 13, 6559–6578, https://doi.org/10.5194/amt-13-6559-2020, 2020.

Dataset containing attenuation data from 6 E-band CMLs at Zenodo repository:

Martin Fencl, Michal Dohnal, Martin Mudroch, and Vojtěch Bareš: Data and code for the paper Atmospheric Observations with E-band Microwave Links – Challenges and Opportunities, https://doi.org/10.5281/zenodo.4090953, 2020

Water vapor retrieval with K-band CMLs:

David, N., Alpert, P., and Messer, H.: Technical Note: Novel method for water vapour monitoring using wireless communication networks measurements, *Atmospheric Chem. Phys.*, 9, 2413–2418, https://doi.org/10.5194/acp-9-2413-2009, 2009